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Author - NORMAN BELASCO,  
Section Head,  
Crew Systems Division,  
NASA - MSC

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Author's Mailing Address - Room 131  
2002 Wayside  
Houston, Texas

7 853 July 65

Phone Contact - Area Code 713 WA 8-2811  
Ext. 4221 through 4224

## CREW TRANSFER IN ORBITING SPACECRAFT

Norman Belasco\*

There are two primary problems common to the transfer of crew members in space whether it be between vehicles in close proximity, or between compartments of a single large vehicle. These are: (1) maneuverability/locomotion/propulsion in zero g, and (2) protection and support during transfer.

This paper integrates pertinent results of independent studies; each study considering important factors of the two primary problems.

### INTRODUCTION

There are two primary problems common to the transfer of crew members in space, whether it be between vehicles in close proximity, or between compartments of a single large vehicle. These are:

- (1) maneuverability/locomotion/propulsion in zero g, and
- (2) protection and support during transfer.

In all transfer cases, the former must be accommodated in some manner since it appears impractical to move the vehicle about the crew member. For the latter, except for cases of transfer which are completely in, from, to, and through pressurized compartments of the same vehicle or joined vehicles, a personal protective enclosure having an environmental control capability is required.

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\*The independent studies whose results are presented in this paper were initiated while the author was employed as Supervising Engineer of Advanced Life Support Engineering, Missile and Space Division, General Electric Company. The studies were continued and updated since the author's recent position change to the Crew Systems Division, NASA Manned Spacecraft Center, Houston, Texas.

This paper integrates pertinent results of independent studies; each study considering important factors of the two primary problems. The material presented in the paper includes discussions and data relative to:

1. The factors that limit the time of transfer in a pressurized suit and the means for increasing allowable transfer time.
2. Techniques of transfer.
3. Design concepts of equipment for maneuvering/locomoting/stabilizing and propelling.
4. Geometric dimensions of an inflated and occupied space suit (Table 1 and Figs. 1-3).
5. Configurations and dimensional requirements of air locks, hatchways, and transfer tunnels for ingress, egress, and performance of assigned tasks (Figs. 4-6).
6. Detailed prediction of mobility that will be achieved in early extravehicular space-suit design.

#### LIMITATIONS IMPOSED UPON THE CREWMAN BY ENVIRONMENT AND PROTECTIVE EQUIPMENT

Design goals of the prototype extravehicular personal protective enclosures (space suits) presently being developed are primarily (1) increased mobility, (2) adequate thermal balance, and (3) material and fabrication integrity. The most critical single factor upon which development emphasis is being placed is thermal balance.

##### Thermal Balance Limitations

Because of the radiation heat sink available in space during extravehicular transfer, the suited astronaut will transfer much of his generated metabolic energy to black space. Calculations indicate that with an initial air temperature of 75° F in the suit, a suited astronaut will provide a net radiation in the vicinity of 675 Btu/hr. This radiating process from the suit is dependent on the radiation transfer between the man and his suit as well as the natural convective transfer of the pressurized

gas ( $O_2$ ) within the suit. For the heat storage in a 175-lb human, calculations indicate that a total heat storage of 330 Btu is possible before high body fever will seriously reduce the efficiency of the astronaut.

Considering all heat-transfer mechanisms, a total heat-transfer capability of 675 Btu/hr can be available in early space-suit designs for an astronaut situated in space in a pressurized but virtually unventilated space suit. In addition, the man is capable of storing another 330 Btu of heat. Hence, from a thermal-balance standpoint only, and neglecting other related factors, an astronaut working at a rate of 300, 500, or even 700 Btu/hr should be capable of working in space (in orbit) without appreciable gas ventilation for periods of time approaching  $\frac{1}{2}$  hour. For work rates of 300 to 500 Btu/hr, a steady-state condition of heat flow from the astronaut to black space is quite possible. In the case of the 700 Btu/hr work rate, an exposure period of under  $\frac{1}{2}$  hr appears to offer no excessive discomfort (from a thermal viewpoint only). However, when positive information as to longer work periods in space is available, a transient analysis can be conducted with computer facilities to establish an accurate profile of man temperatures versus time.

#### Suit Occupancy Limitations

Testing, directly applicable to transfer time limits, was conducted with a MK IV full-pressure suit. Test objectives were to determine the suit-system factors which limit transfer, extravehicular duty tours, and survival time, when the suit is being used without a back pack or oxygen supply source. The limiting factors were anticipated to be thermal balance,  $CO_2$  buildup, oxygen partial-pressure depletion, and total-suit-pressure degradation resulting from suit leakage.

Analysis of initial test results substantiates the preceding discussion in that thermal balance should not become a stringent limiting factor in extravehicular crew transfer. The results show the critical factors that will limit use of the suit without

environmental control system support are  $O_2$  depletion and/or total-suit-pressure degradation. The  $CO_2$  buildup, although exceeding the desirable operational range, does not become critical before either  $O_2$  or pressure depletion. Suit leakage rate itself will determine the first critical factor - suit pressure degradation or  $O_2$  depletion. The curves in Figs. 7 and 8 show the plotted results of one of the suit tests. A comparison shows that with the stated leak rate (approximately 1,700 cc per minute at 3.5 psig), oxygen depletion is most critical and thus is the limiting factor for time of useful consciousness. Further examination of these curves as related to various pressure depletion times as a function of leak rate (Fig. 9) shows that either  $O_2$  depletion or pressure depletion can be the critical factor that limits use in this operational mode. Fig. 10 is a photograph of the test in progress.

#### Simple Techniques for Increasing Transfer Time

For the transfer mission, a 1-lb oxygen supply bottle and regulator should be uncoupled from the back-pack system (as a module) and used.

Tests have substantiated the validity of this approach, since the time-limiting factor in the suit tested is the  $O_2$  supply (when an open-cycle operational mode is used, that is, low flow rate of  $O_2$  to the suit to provide primarily for leakage make-up). Open-cycle operation compensates for the  $CO_2$  buildup so that an extremely critical  $CO_2$  concentration is not reached during this operational mode. In the tests conducted, the time of useful action, based on use of the bottle and regulator module from the back pack, is a maximum of approximately 25 minutes. (This period includes a total of 20 minutes while the  $O_2$  bottle is in use, plus up to 5 minutes without  $O_2$  flow during which time the suit pressure will be diminishing and  $CO_2$  will be building up to a critical level.) By using these results as representative criteria, "normal" usage in this activity mode can be estimated at approximately 20 minutes; thus, transfer tasks and/or procedures should not exceed the difference between safe return and 20 minutes.

Specifically, transfer tasks must be terminated or aborted before the point of "no return" is reached.

#### CAPABILITIES AND LIMITATIONS OF CREWMEN IN PROTECTIVE SUITS

Crew-transfer task requirements will best be accommodated by a suit design in which standing, walking, bending, kneeling, and sitting can be possible. The efforts for producing early extravehicular space suits are concentrating upon increasing mobility, primarily for the hip and shoulder-motion ranges, and minimizing the forces required to achieve the broader ranges of motion. The ultimate will be achieved when the range of motion at both the shoulder and hip approximate the wide range of the normal unsuited human.

##### Mobility Test Results

Figs. 11 through 20 illustrate various typical dynamic motions of the test subject. The photographs can be scaled to define the spatial envelope of the particular position of the astronaut and the limits and capabilities of his mobility. In most of the studies, the test subject was told to flex to the limit of his ability to illustrate maximum contraction or expansion of body members.

##### Anticipated Mobility of Early Extravehicular Suits

To express the anticipated mobility of early space suits, a list of representative functional gross body movements (Table 2) was prepared. The table contains complete test data obtained from tests conducted with the Mercury suit at 3.5 and 1.0 psig. A hidden significance of the increased mobility at reduced pressures conveys the potential for a suit design that incorporates mechanical pressurization techniques in conjunction with the pneumatic pressurization techniques.

#### EXTRAVEHICULAR TRANSFER TECHNIQUES

The method of transfer to a parent vehicle from support vehicles

can be accomplished by any one of a number of manned propulsion capabilities or by powered propulsion.

#### Short Spans

When the distance to be traversed is small (under 100 feet), powered devices require micro-thrust ranges and "catcher" devices which render their use impractical. For these cases, transfer can be successfully consummated within allowable time limitations by any one of the following simple manual devices: lines, telescoping pole, telescoping ladders, net, or personnel tunnels. Artists concepts of net and personnel tunnels are shown in Figs. 21 and 22.

#### Long Distances

For transfer between vehicles exceeding a separation of 100 feet, devices, vehicles, and techniques making use of powered propulsion are preferable. In the space environment, movement occurs without damping. Accordingly, all devices must provide micro-thrust capability so that minimum thrust can be employed during acceleration and deceleration.

The propulsion devices should be manually controlled and mounted to the suit system, in a manner which inherently tends to improve alignment and thus reduce the moments about the body which give undesirable rotations instead of translation. Both acceleration and deceleration can be obtained from the same thrust device by re-orienting it with respect to the velocity vector. This type of system would require skill and prior training on the part of the operator. Impact against other men, against the operator's mother ship, or against other employed devices vividly represents a hazard. Bumper and catcher devices, which will decelerate the man appropriately, are necessary for these applications. If micro-thrust levels can be achieved, such restraint mechanisms may be minimal. Early experimental work with personal propulsion systems has indicated the need for considerably more development to provide the thrust levels and control required for performing extravehicular tasks. Figs. 23 through 26 show artists concepts

of personal transport devices.

## EXTRAVEHICULAR TRANSFER TECHNIQUES

### Static Anthropometric Dimensions

The spatial requirements of a space suited crew member and his movements influence the design of hatches, locks, tubes, and confined work areas. For transfers to be consummated, an initial set of clearance dimensions and configurations must be selected which will permit the unrestricted passage of the pressurized suited crewman.

Since early extra-vehicular space suits are presently unavailable, measurements were taken of a Mercury Full Pressure Suit with attached backpack. The suit pressure was 1.0 psi which again employed the aforementioned philosophy, i.e., simulation of anticipated increases in mobility through reduction in suit pressure.

Table 1 and Figures 1, 2, and 3 show the tabular data, and the dimensional profiles from which the data were extracted.

### Crew Transfer Clearance Dimensions

Ingress and egress clearance dimensions in both zero "g" and sub-gravity are determined by these factors:

- . transfer orientation relative to operator's centerline;
- . position of operator while transferring;
- . length of passage in relation to the operator's spatial envelope.

Orientation and geometric configurations are the most rigid



of these factors (being dictated by the structure of the space station), whereas man will be the determining size factor. To analyze the relationship of these factors, a group of five basic geometric configurations is used as a framework within which design criteria can be considered. The basic types are representative of those commonly utilized in vehicle design and are illustrated in Figures 4, 5, and 6. They are:

Types A and B - Interconnecting hatches parallel to the crew members vertical centerline.

Type C - Interconnecting hatchway less than 18 inches long.

Type D - Interconnecting hatchway more than 18 inches long.

Type E - Representative Air Lock

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Table 1

## CREW TRANSFER STUDY - STATIC ANTHROPOMETRIC DATA

## Standing Position

Code	Item	Inches
A	Height	$70\frac{1}{2}$
B	Eye	$65\frac{1}{8}$
C	Shoulder	$57\frac{3}{4}$
D	Knuckle	32
E	Arm span	$68\frac{7}{8}$
F	Shoulder breadth	$21\frac{1}{4}$
G	Extended arm	$31\frac{13}{16}$
H	Chest depth	Not obtained
I	Chest depth plus back pack	$19\frac{1}{16}$
J	Backpack depth	Not obtained

## Seated Position

K	Seated height (from ref. point)	$36\frac{5}{16}$
L	Shoulder height	$24\frac{3}{4}$
M	Elbow	9
N	Knee	$23\frac{3}{4}$
O	Buttock-knee	$24\frac{5}{8}$
P	Hip	$13\frac{3}{4}$

Table 2

## FUNCTIONAL GROSS BODY MOVEMENTS AT 1 PSIG

## Easy to Perform

Fall to prone position from standing position on a mat.

Roll from supine to prone position

Raise from a prone position to hands and knees.

Crawl forward 6 feet.

Crawl backward 6 feet.

Execute a 360-degree turn in place on hands and knees.

From hands and knees, raise to sitting position with feet extended with no assistance. (No assistance required)

From hands and knees, raise to sitting position with feet extended with assistance; namely, the use of a wall chair or physical support. (No assistance required)

Raise from hands and knees to an upright position with the use of wall chair or other physical support.

From the upright position, lower to hands and knees without help.

From the upright position, lower to hands and knees with the use of wall chair or other physical support (No assistance required)

From the upright position, lower to a deep squat.

Raise from the deep squat to the upright position (note: with or without assistance). (No assistance required)

Walk 50 feet on level grade at slow speed, turn 180 degrees and return.

Walk 50 feet at maximum speed straight away, if possible.

Walk sideways by side-stepping at least 5 feet.

Walk backwards 5 feet.

Walk up a standard staircase with 8-inch risers for at least four steps; turn on the steps and walk down with or without handrails.

Standing broad-jump. Distance 38½ in.

Three-step jump. Distance 38½ in.

Jump down from a 1-foot platform.

## Difficult to Perform

Roll from prone to supine position wearing back pack.

Side-step 4 feet to the right in a hands-and-knees position.

Side-step 4 feet to the left in a hands-and-knees position.

Raise from hands and knees to an upright position with no assistance (no assistance required)

Climb a vertical ladder with 8-inch risers and flat rungs. Climb up four steps and down four steps.

Raise man with a simulated backpack and/or umbilical by the shoulders and drag 10 feet in a straight line.

## Impossible to Perform

Raise man clear of the floor (approximately equal in weight to the subject) and carry for a distance of at least 6 feet.

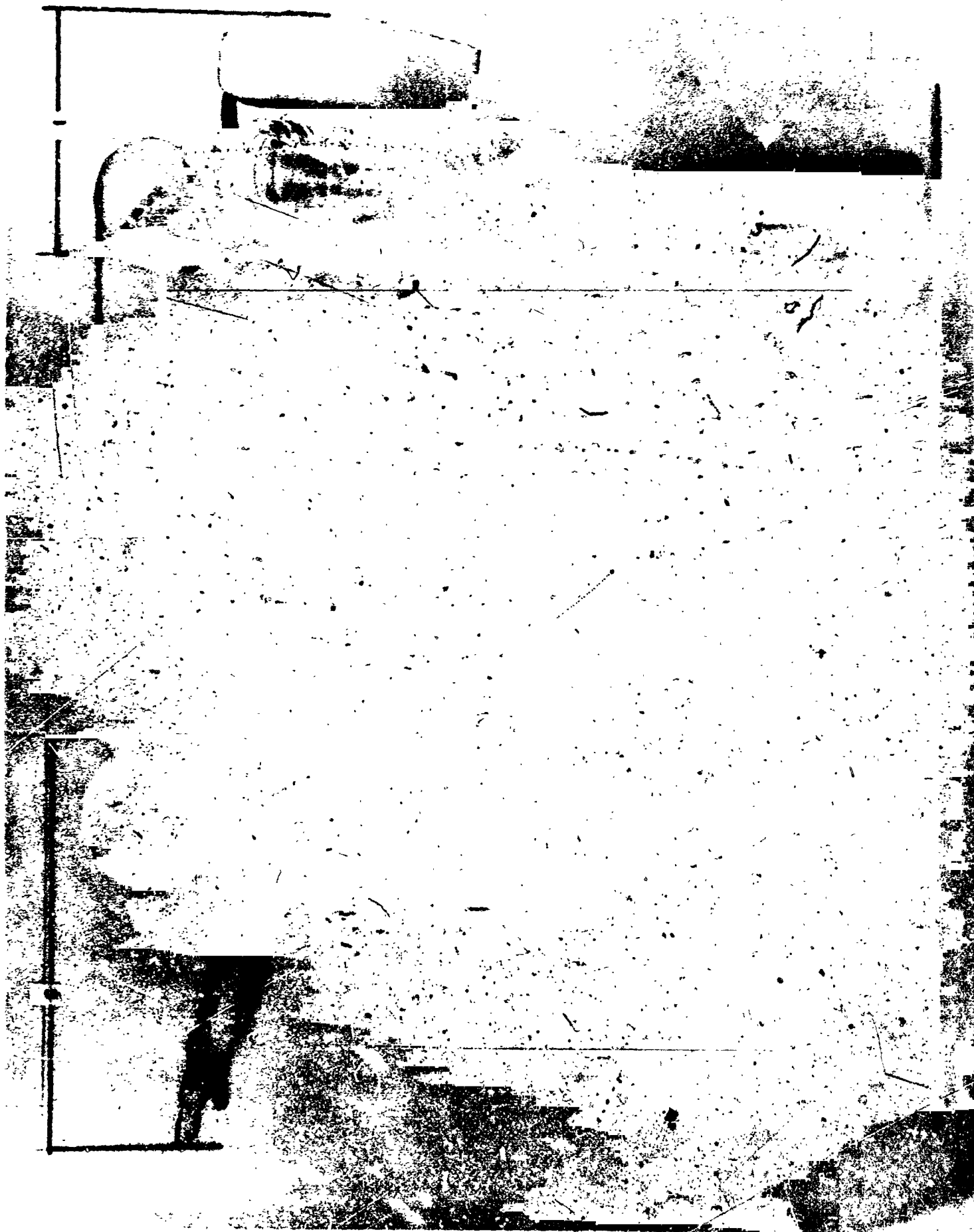






Fig. 3. Gross Section Profile, 1.0 yds

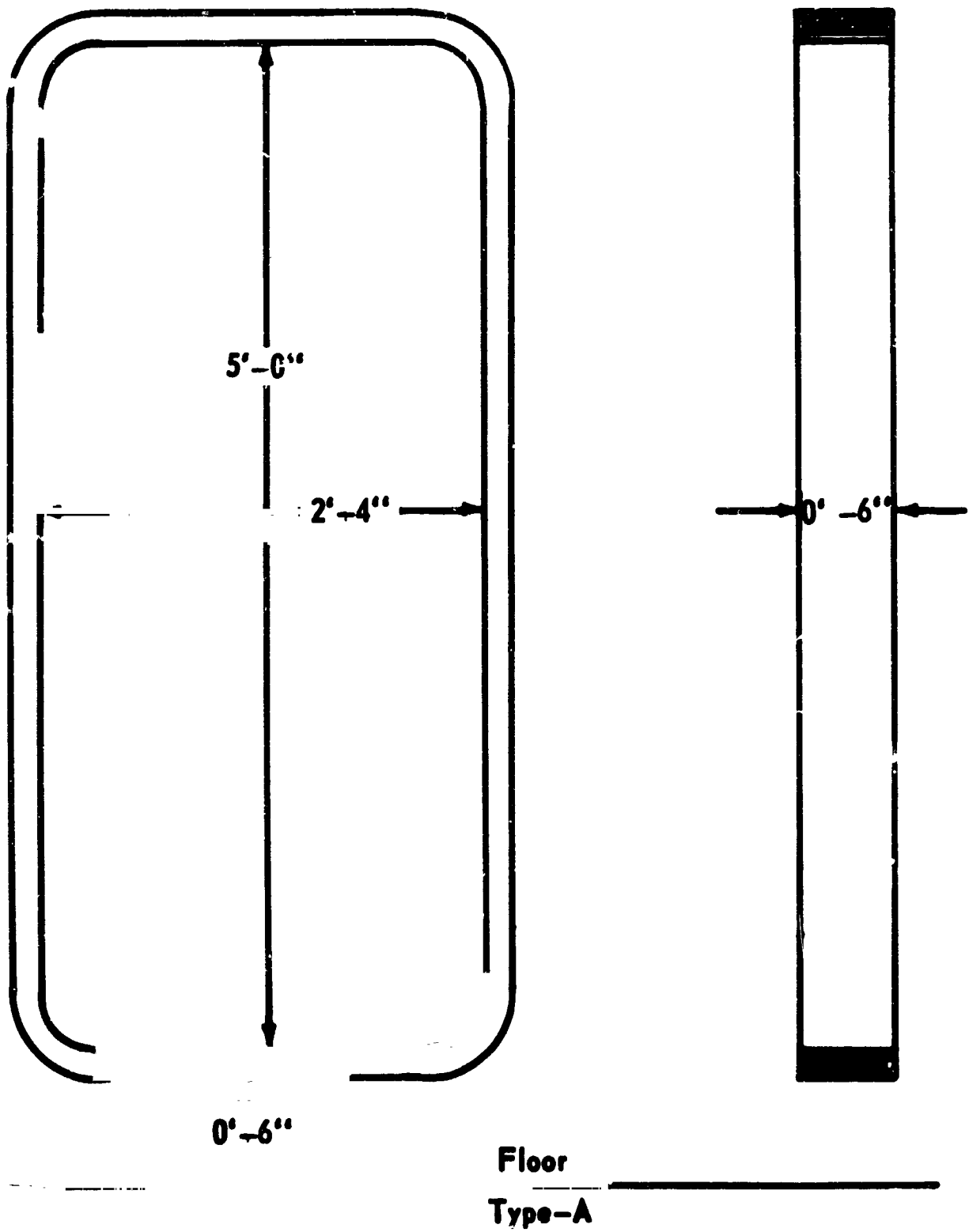


Fig. 4 Basic Geometric Configuration - Minimum Clearance Dimensions

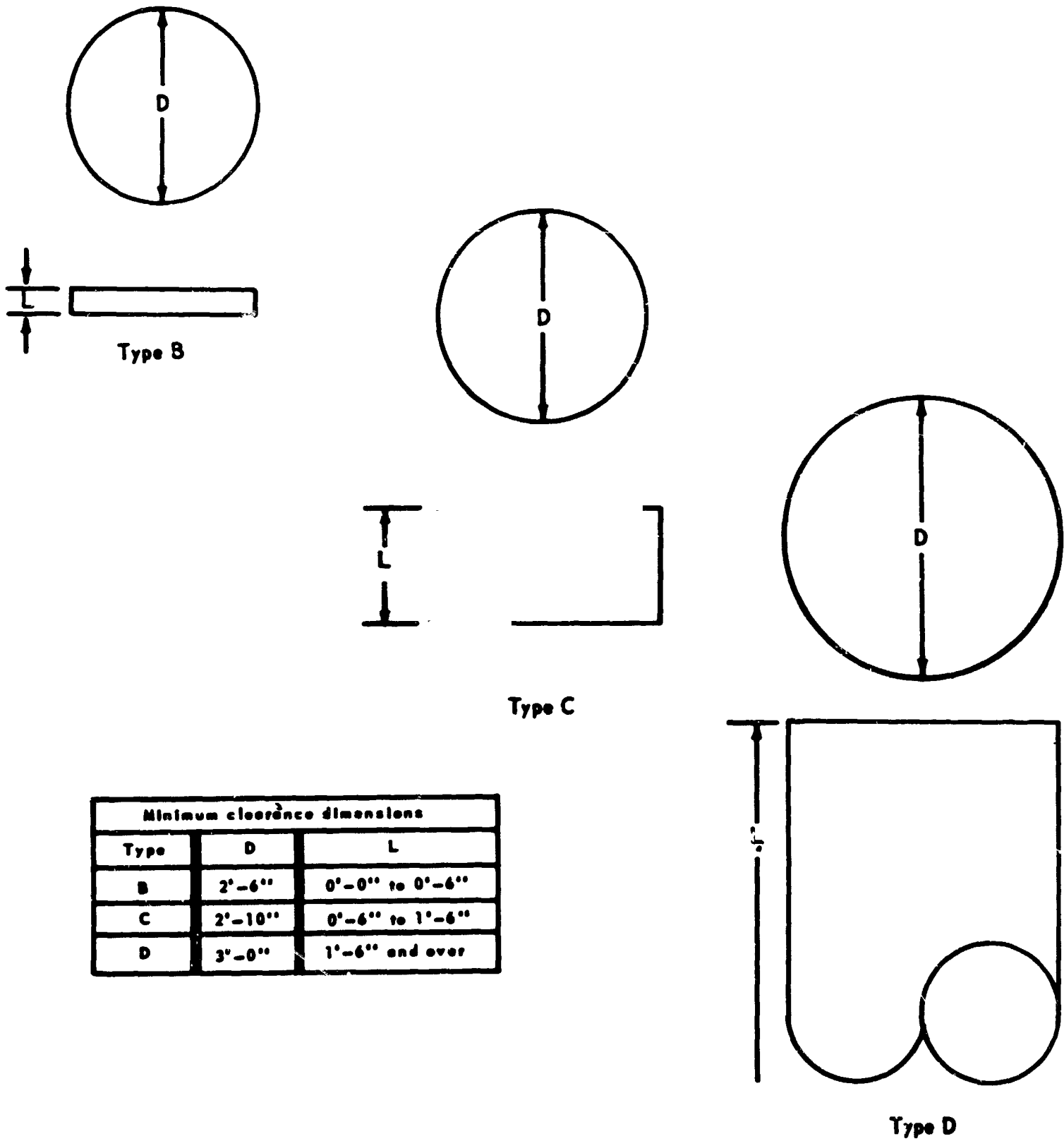
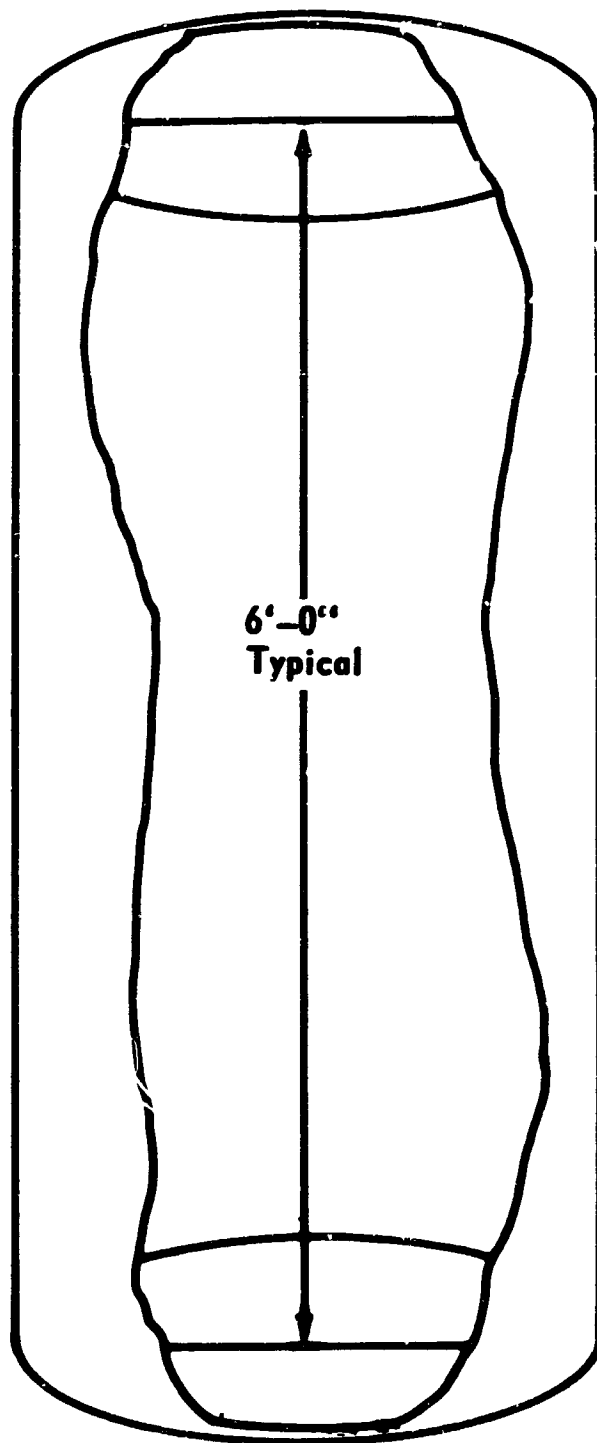


Fig. 5 Basic Geometric Configurations - Minimum Clearance Dimensions





Note—air locks to  
be 3'-0" min. dia.; to  
allow clearance for  
manual operation

Type-E

Fig. 6 Basic Geometric Configuration — Minimum Clearance Diagram

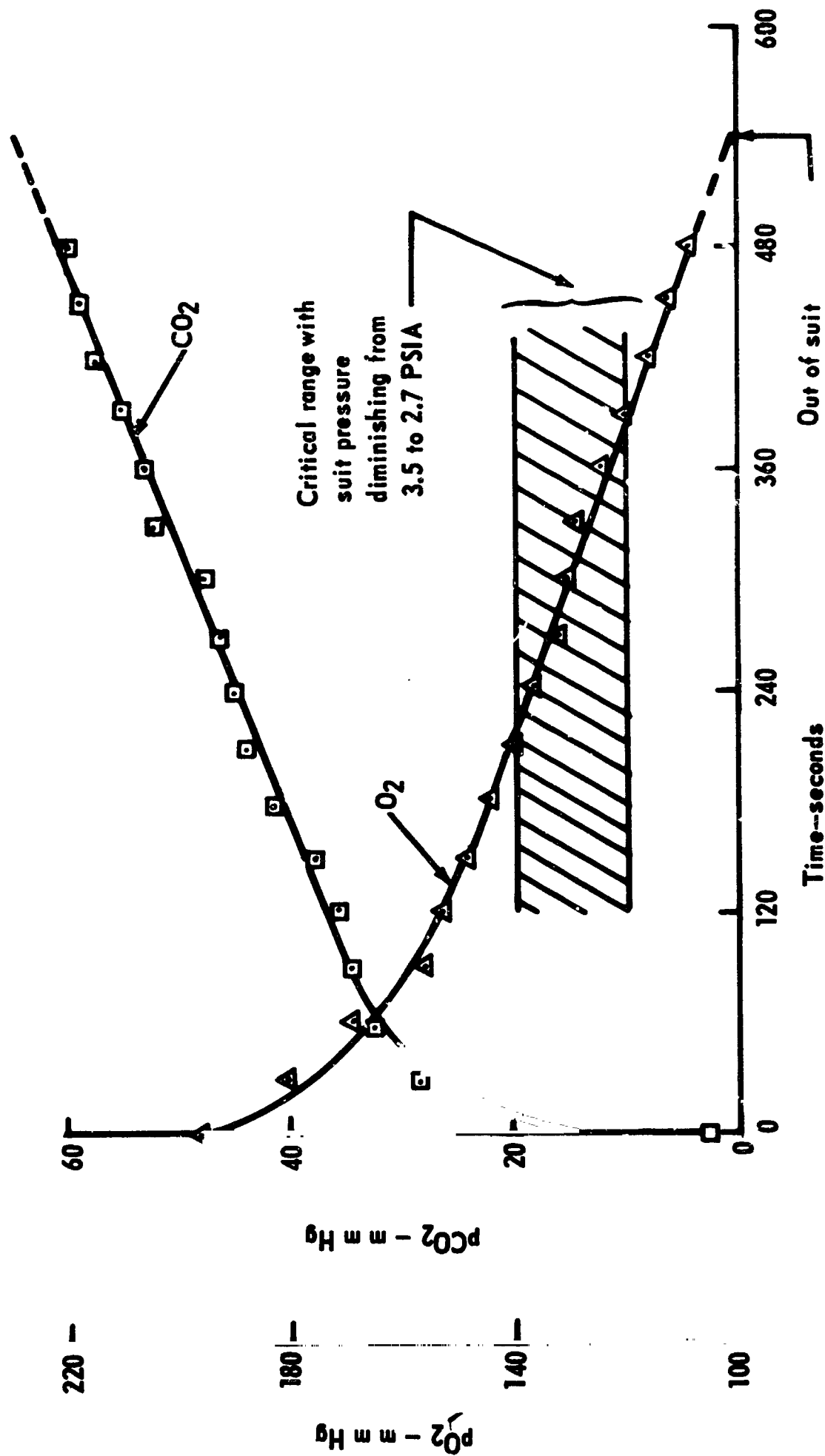


Fig. 7 Graph of  $PO_2$  and  $PCO_2$  Plotted Against Time

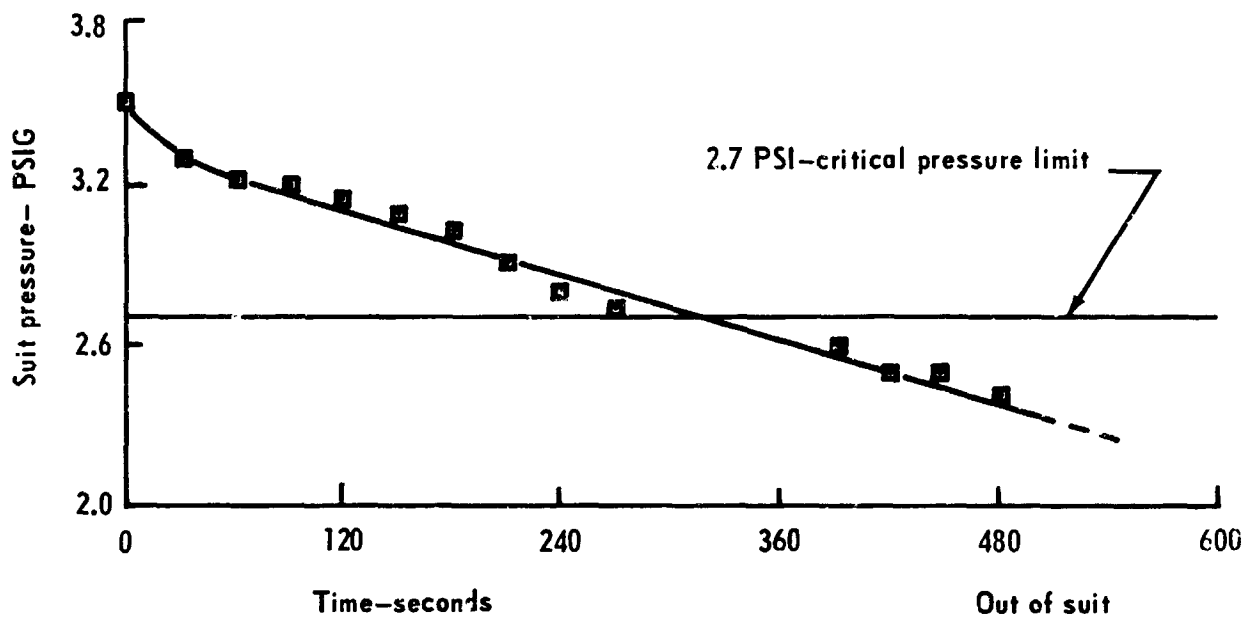


Fig. 8 Suit Pressure Plotted Against Time

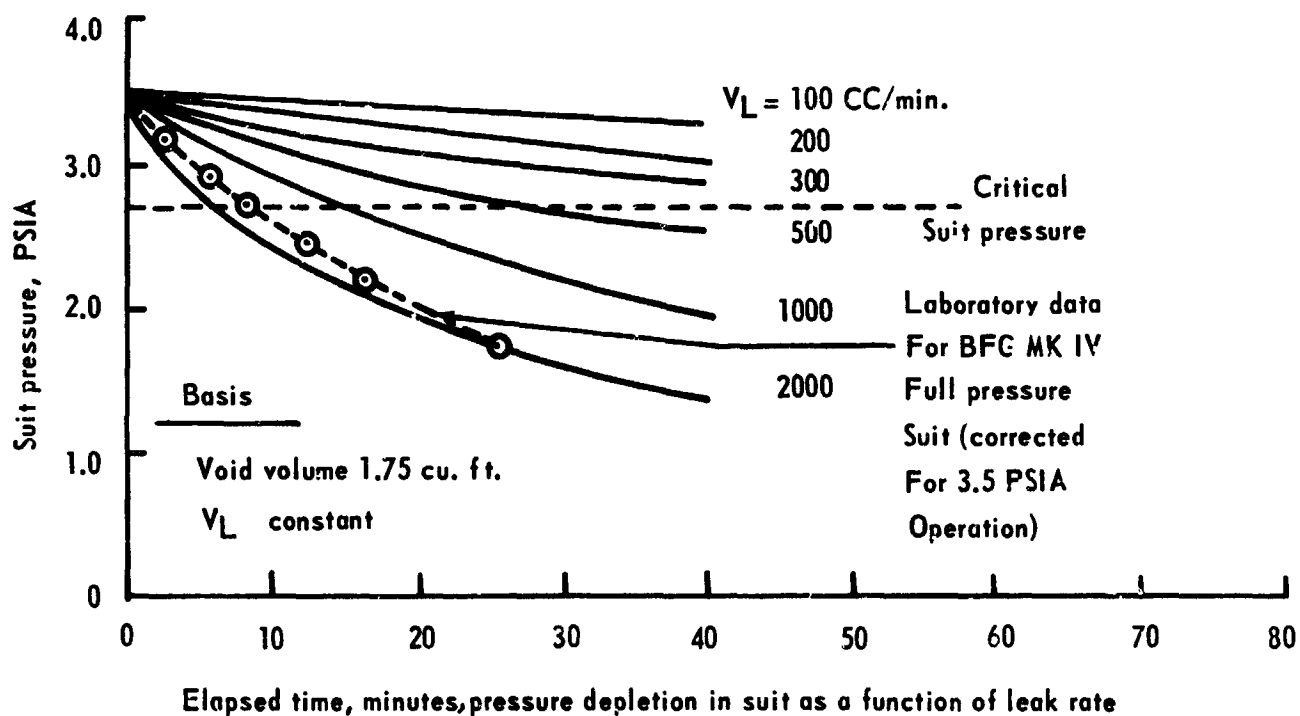


Fig. 9 Pressure Depletion in Suit as a Function of Leak Rate



Fig. 10 Suited Subject Showing Test in Progress



Fig. 11 Maximum Lateral Arm Movement (1.0 psig)

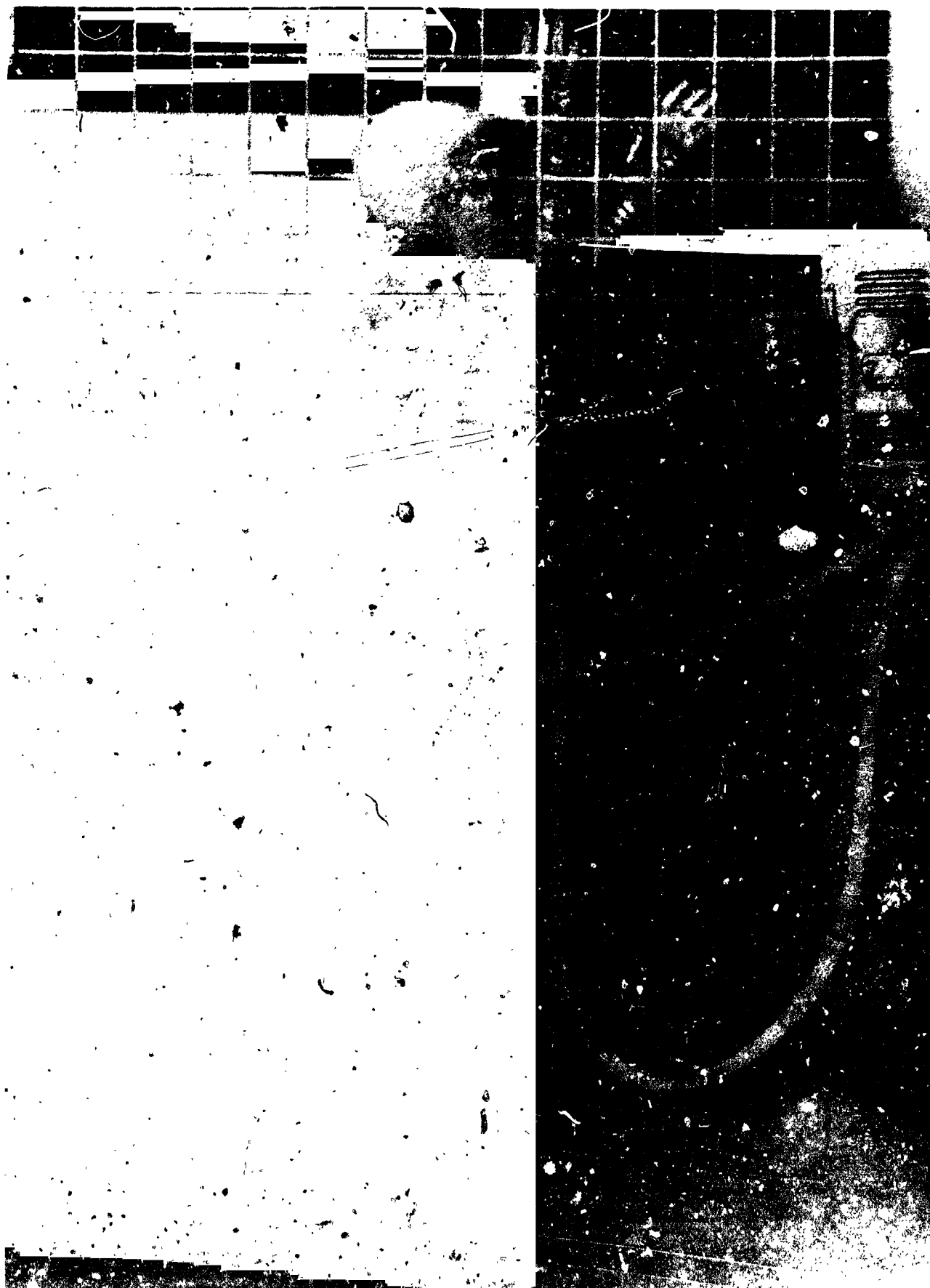


Fig. 12 Maximum Postural Joint Arm Movements (1.0 psig)

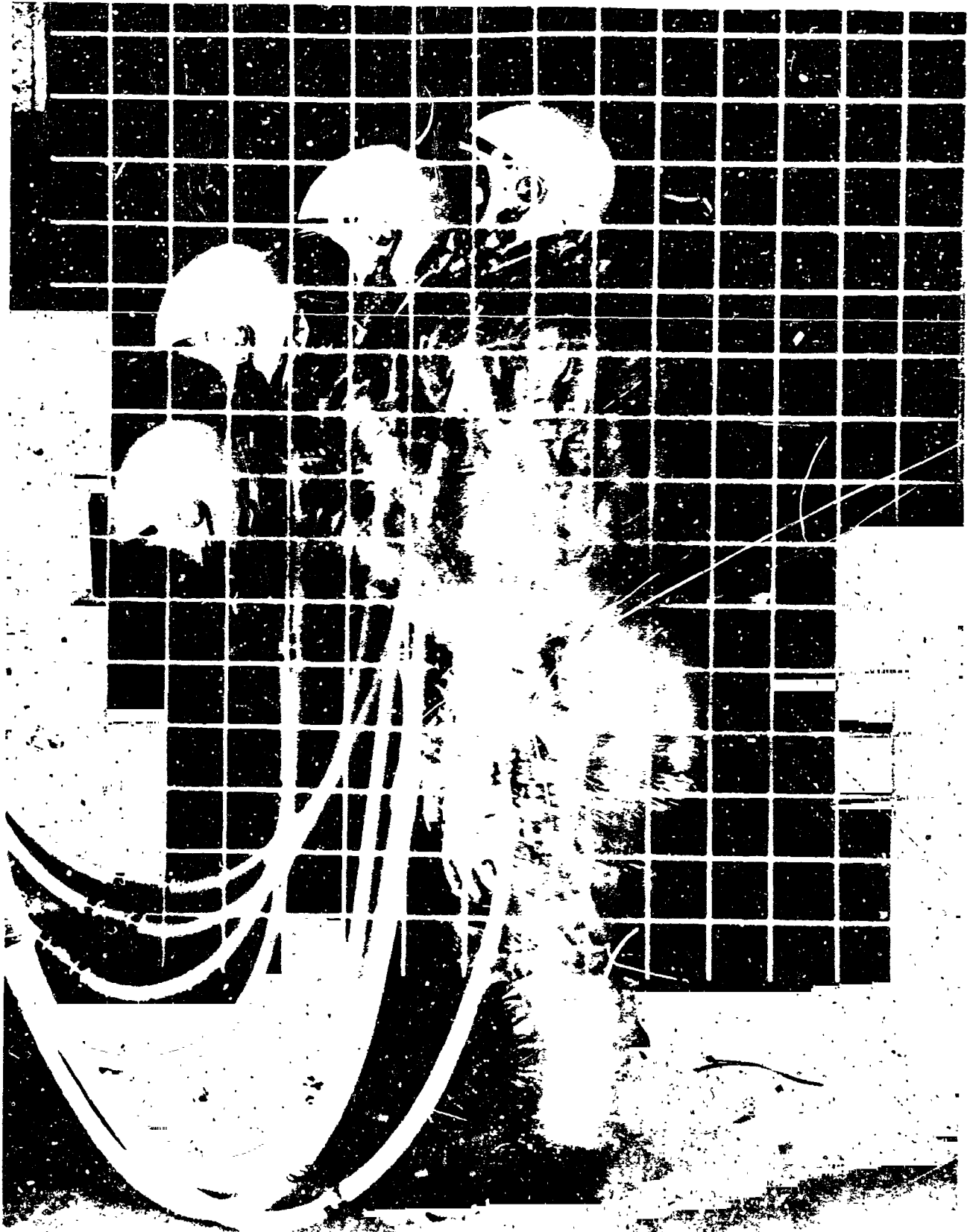


Fig. 15 Maximum Hip Bending (1.0 psig)

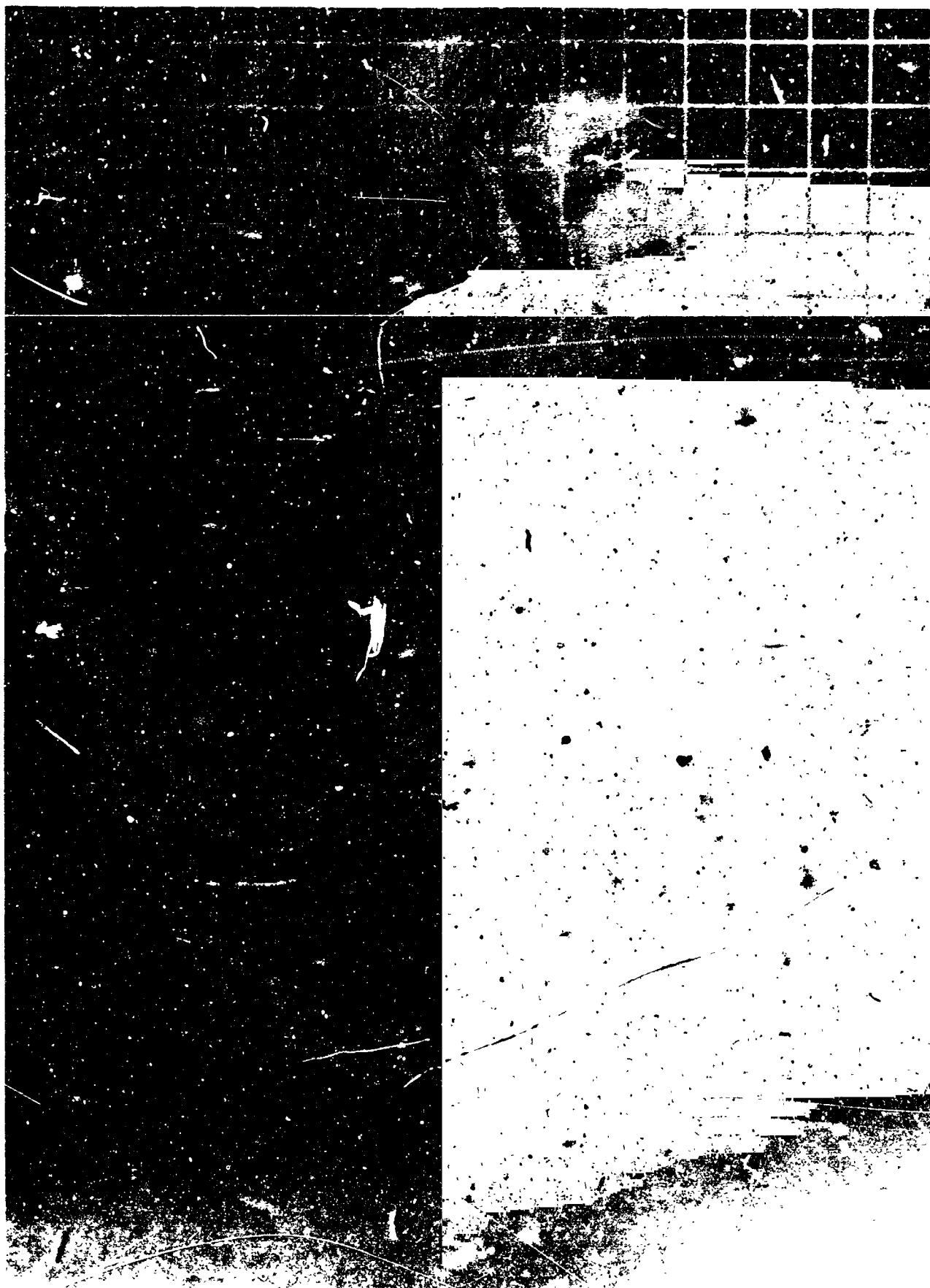
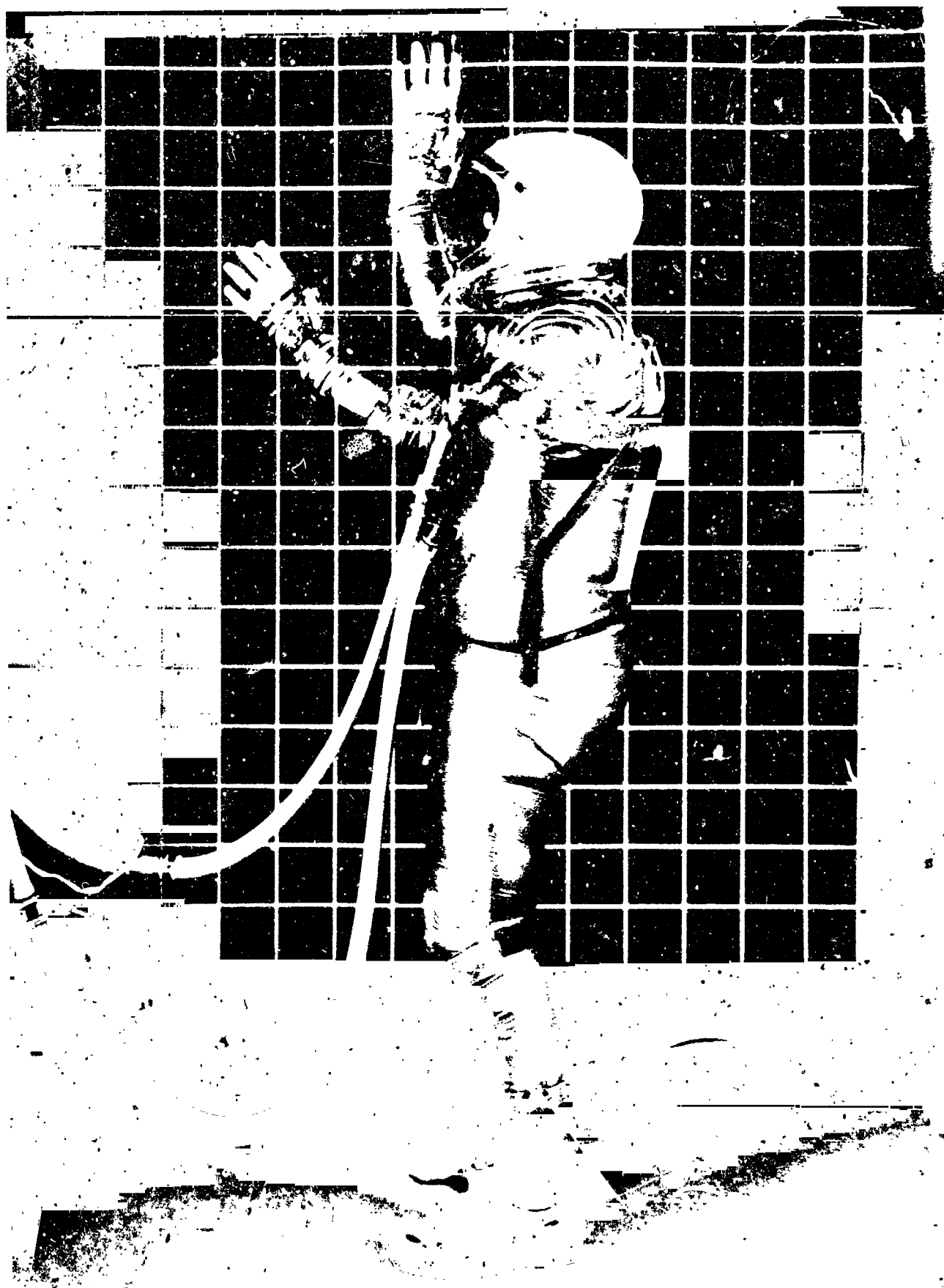


Fig. 14 Pickup Test, Front Bending (1.0 psig)





Fig. 1 Maximum Knee Bend (1.0 point)



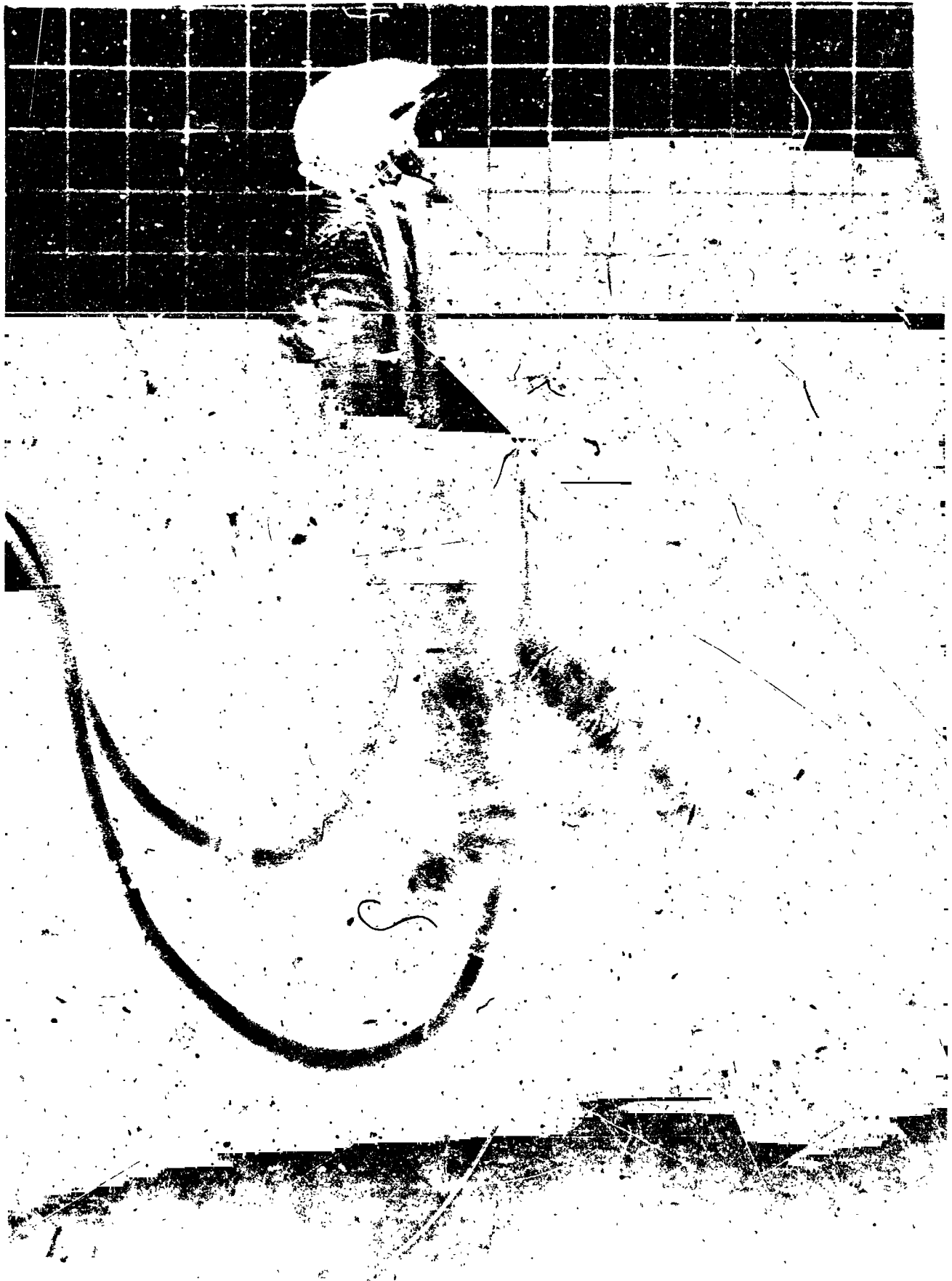


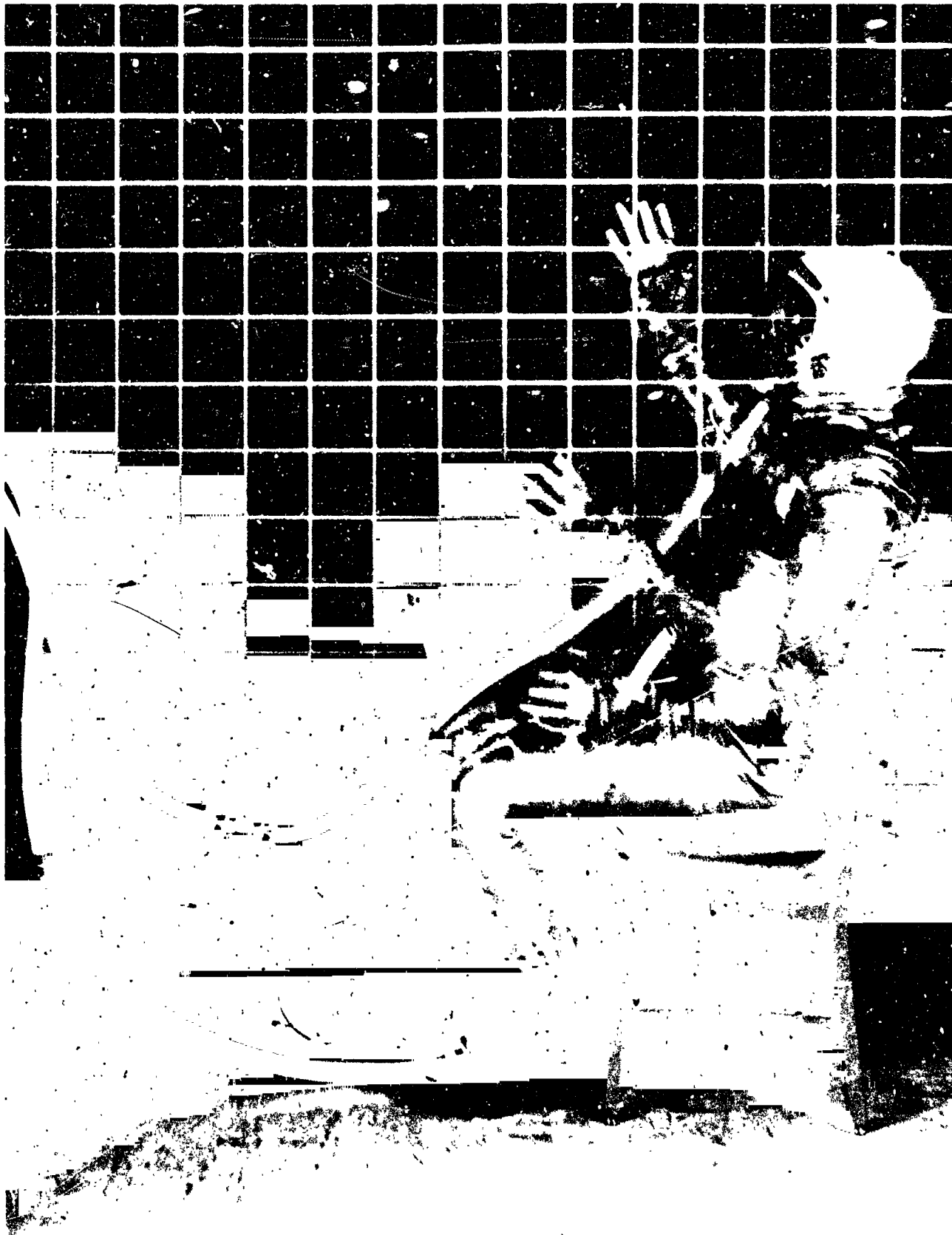
Fig. 17 Maximum Leg Raise (0.8 psig)



Fig. 13 Maximum Leg Bend (0.8 psig)



Fig. 19 Walking Maneuver (0.8 psig)



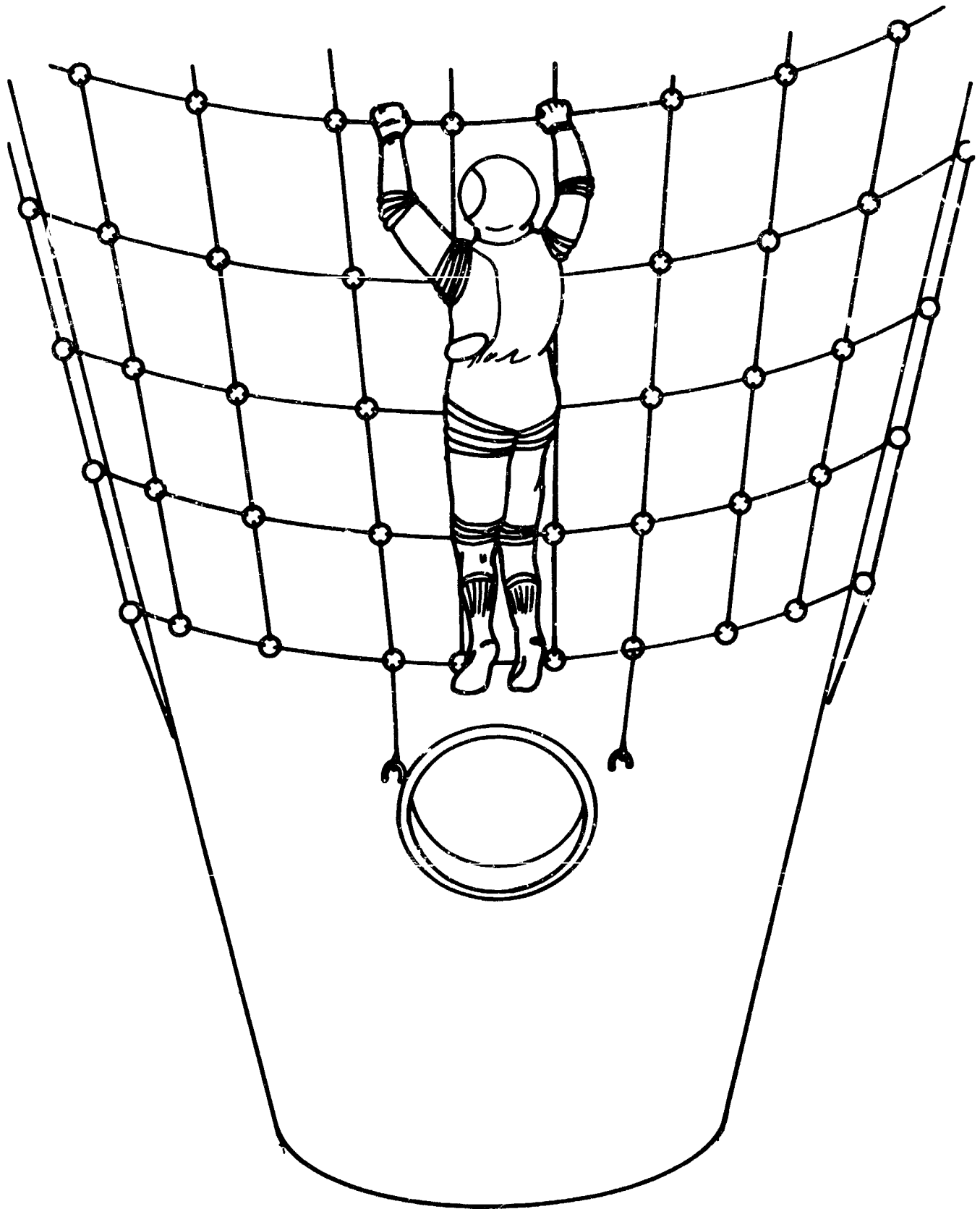


Figure 21. - Net Concept.

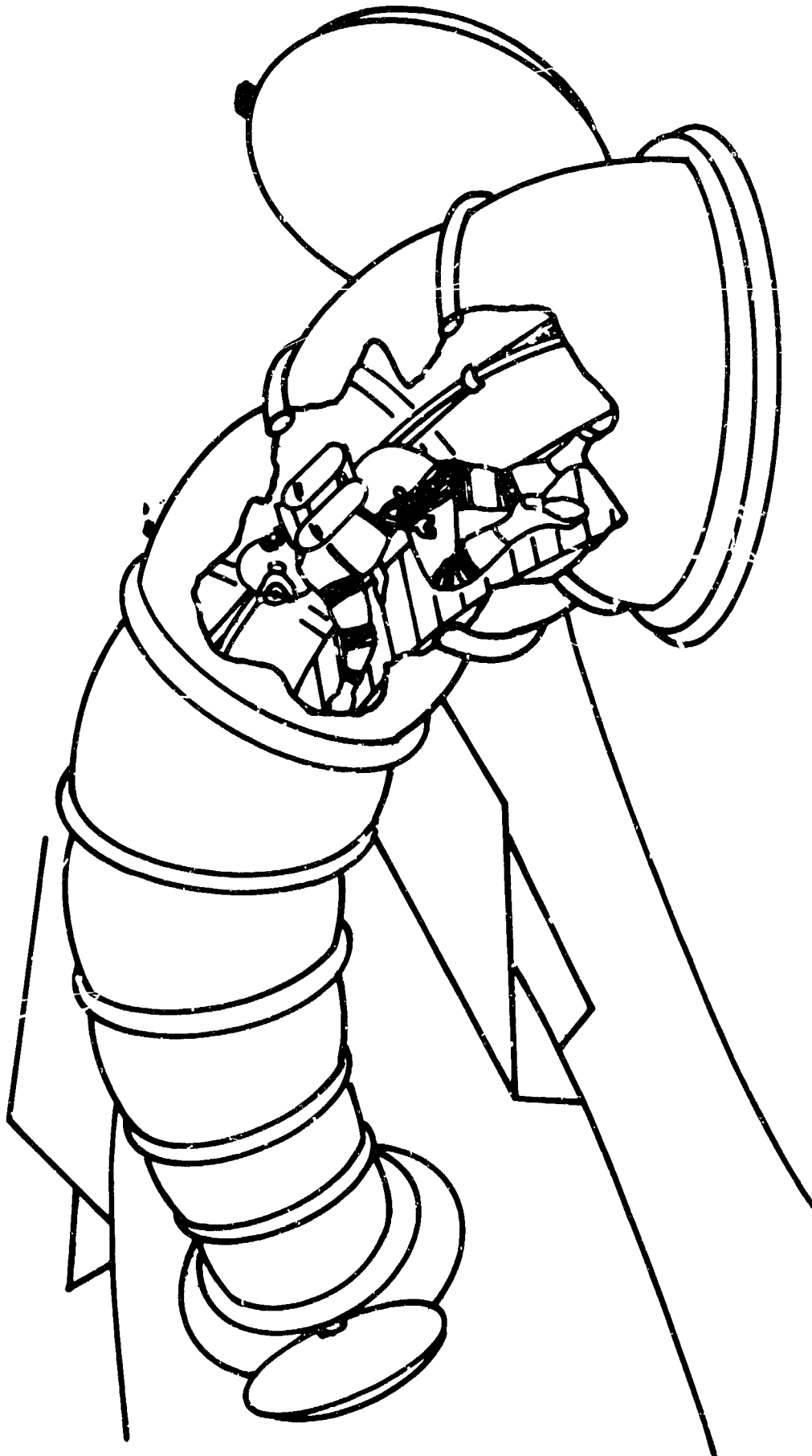


Fig. 22 "Protectube" -- A Lightweight, Highly Versatile,  
Functional Space Shelter





Fig. 23 Spaceman Using Cold-Jet Tractor Rocket Pistol